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IONOSPHERIC IRREGULARITIES PREDICTIONS AND PLUMES CHARACTERIZATION FOR SATELLITE DATA VALIDATION AND CALIBRATION

Eurico De Paula
FUNCATE - FUNDACACAO DE CIENCIAS

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Final Report

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14. ABSTRACT

During the above period the following activities were developed:

- The ionospheric plumes were characterized for 3 longitudinal sectors (east of Brazil, Peruvian coast and pacific zone)using VHF radars and algorithms were developed to represent the plumes in function of solar flux.
- The GPS signal during ionospheric irregularities was analyzed and the effect of the decorrelation was established, the variability of amplitude scintillation pattern was studied and a model alpha-Mi for the scintillation amplitude distribution was generated and its results were compared with the Nakagami-m and Rice models.
- The performance of 6 GPS receivers under scintillation environment was studied.
- An ionospheric prediction model was developed in collaboration with Dr. Emanoel Costa from PUC/Rio de Janeiro.Data from one VHF radar and from GPS receiver was used.
- The correlation of the equatorial S4 scintillation index and S4 under EIA was analyzed.

15. SUBJECT TERMS

-Ionospheric plumes characterization at 3 longitudinal sectors;
- Scintillation prediction

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Final Report
Ionospheric Irregularities Predictions and Plumes Characterization for Satellite Data Validation and Calibration

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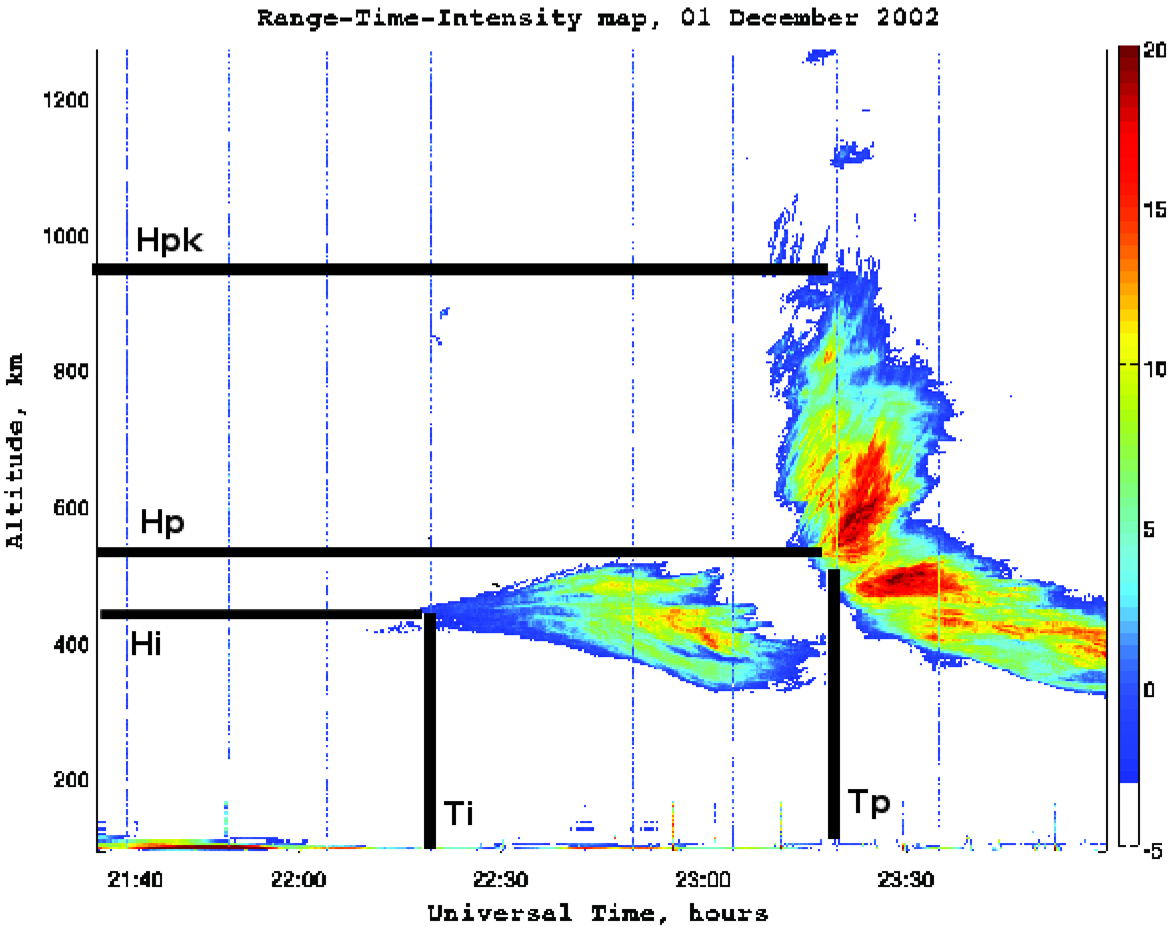
June 19, 2013

Outline

- Plume caracterization
- GPS signal analysis
- Ionospheric scintillation using GPS and VHF radar
- Irregularity prediction model (Emanoel Costa)
- Irregularity prediction
- 6 different GNSS receivers campaign
- References

São Luís, Jicamarca and Christmas Island plumes caracterization in function of solar flux

The following plume parameters were analyzed for São Luís, Jicamarca and Christmans Island:



Hi – Bottom type onset altitude

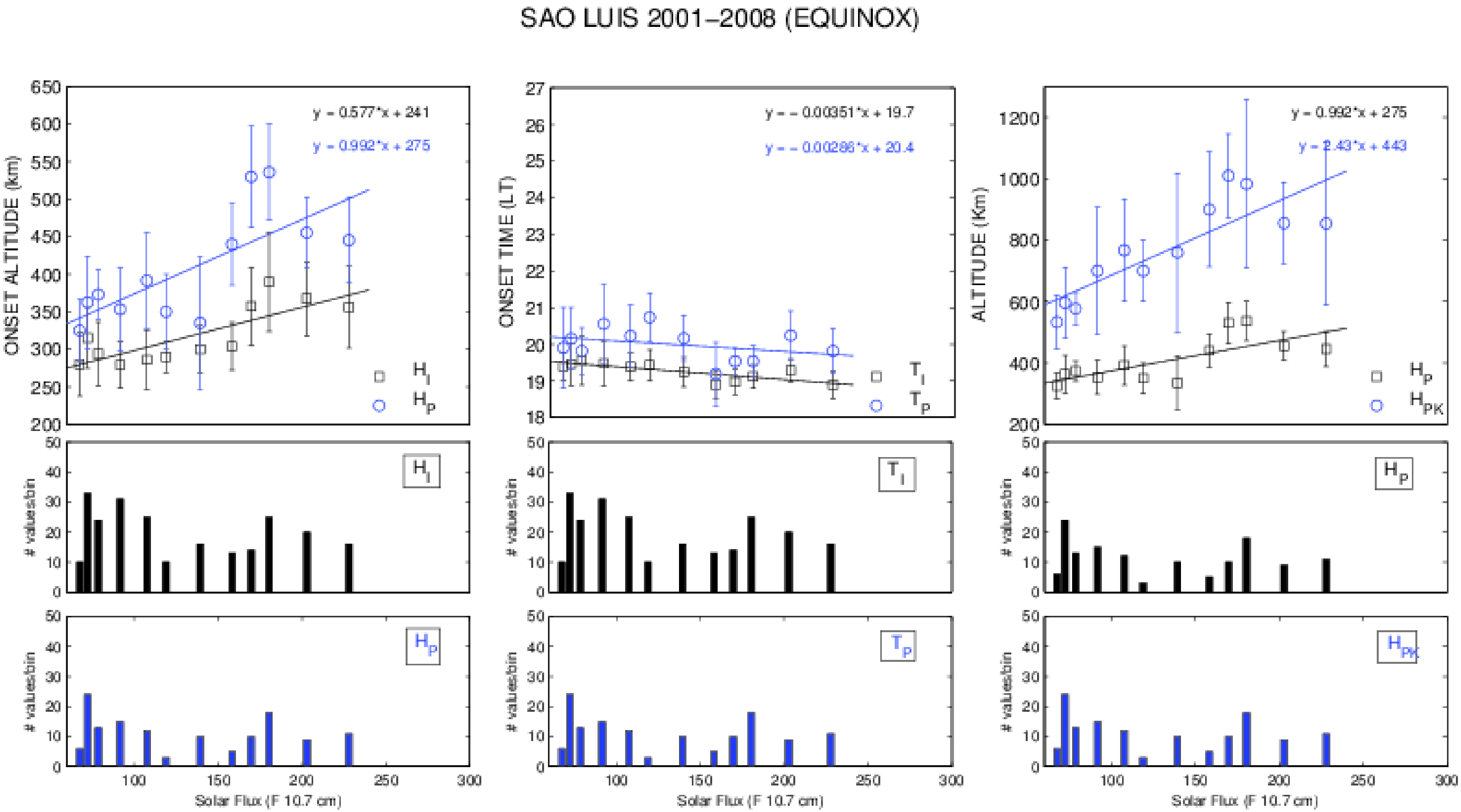
Hp – Plume onset altitude

Hpk – Peak plume altitude

Ti – UT Time for Hi

Tp – UT Time for HP

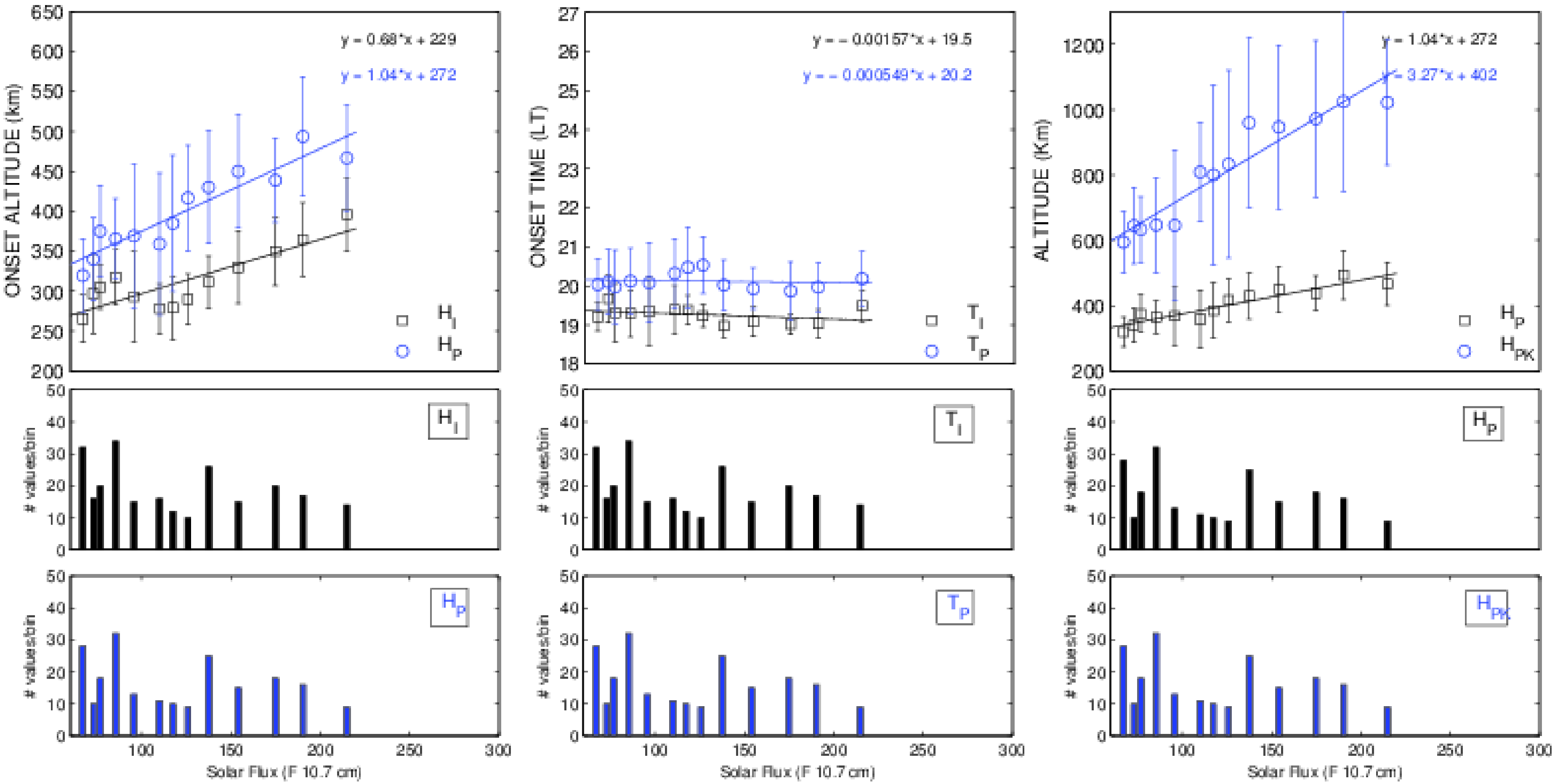
Plumes caracterization in function of solar flux



Onset altitude of bottom-type , plume and plume peak increase almost linearly with increasing solar flux. Onset time decrease with solar flux.

Plumes caracterization in function of solar flux

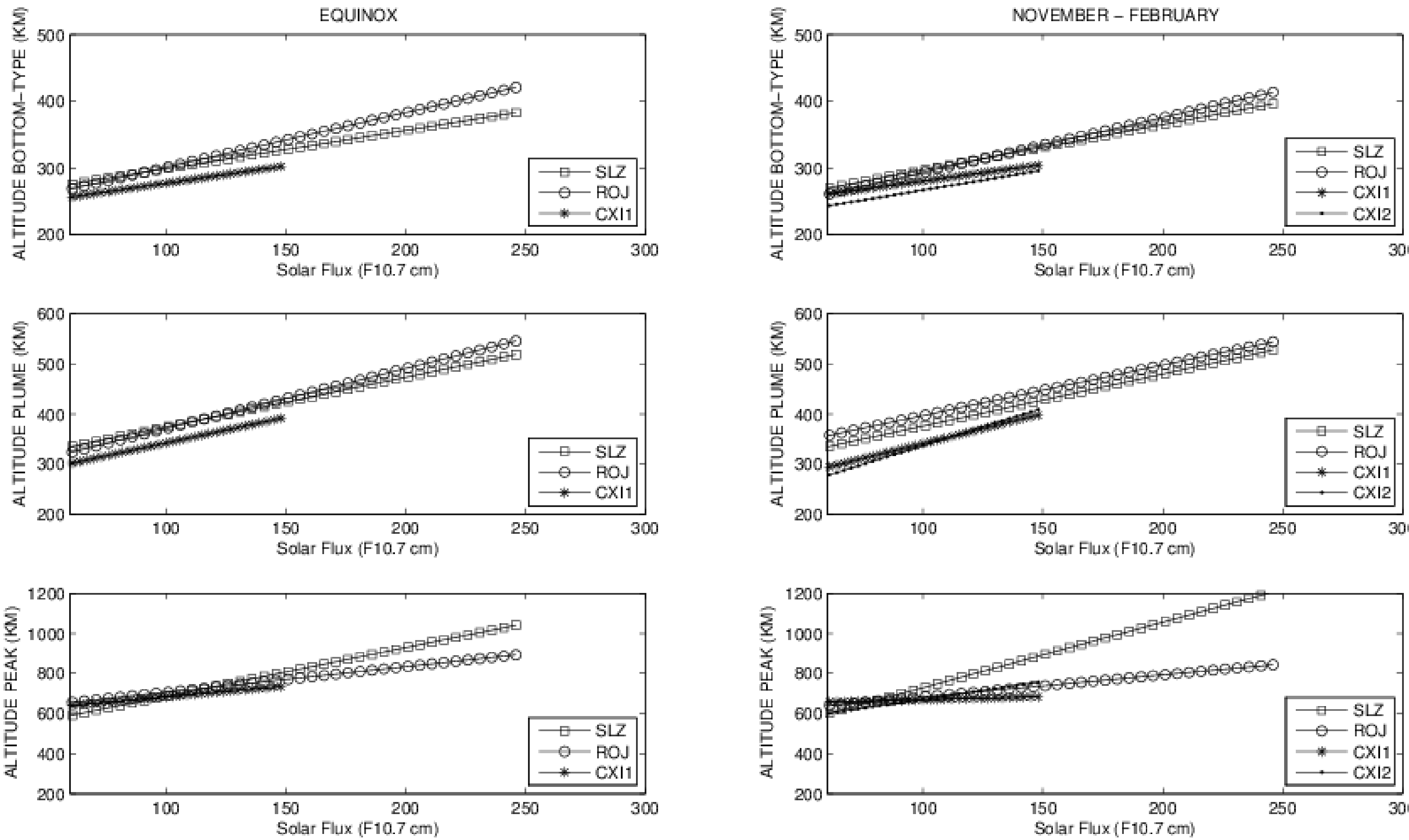
SÃO LUÍS 2001-2008 (NOV-FEB Summer solstice)



Onset altitude of bottom-type , plume and plume peak increase almost linearly with increasing solar flux. Onset time presents almost no variation with solar flux.

Plumes caracterization in function of solar flux

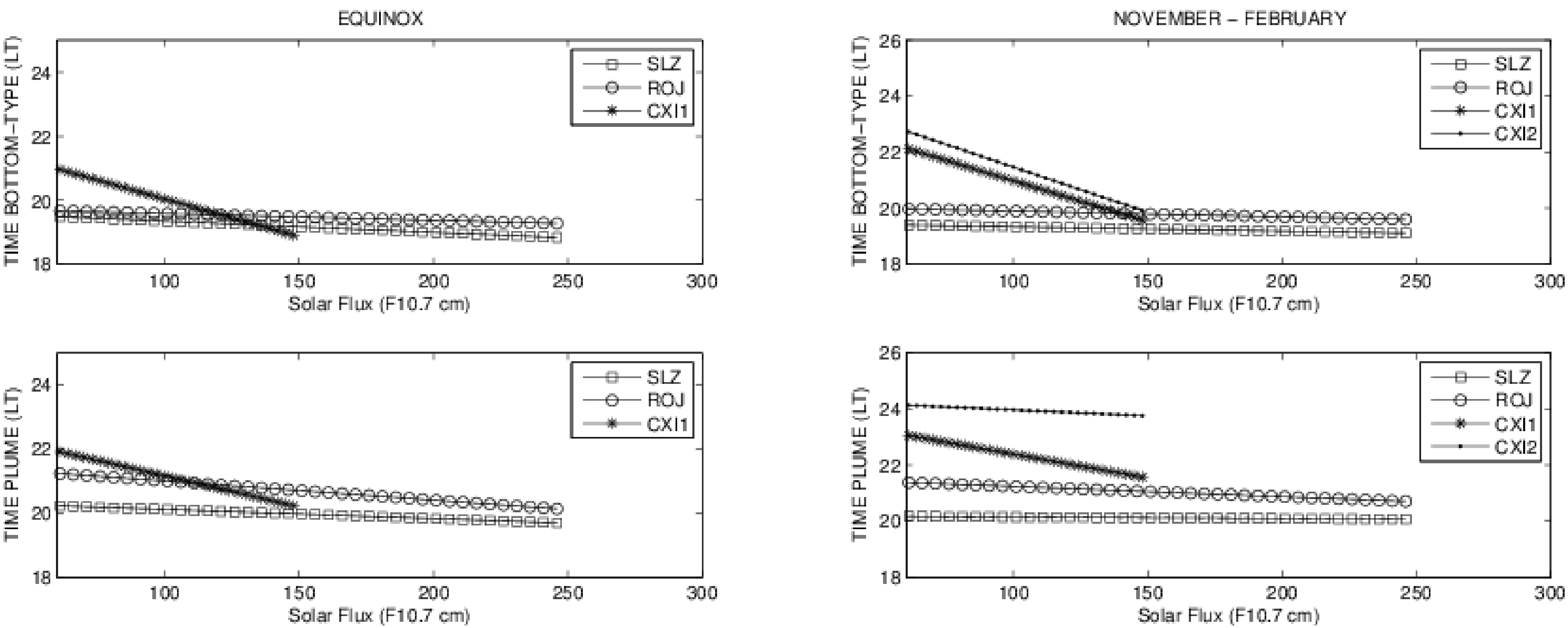
Bottom-type, plume onset and peak altitude variation with solar flux for the 3 stations



Bottom-type and plume onset altitude present similar behavior for the 3 stations, while the plume altitude peak presents smaller inclination for Christmas Island.

Plumes caracterization in function of solar flux

Bottom-Type and plume onset time with solar flux for the 3 stations

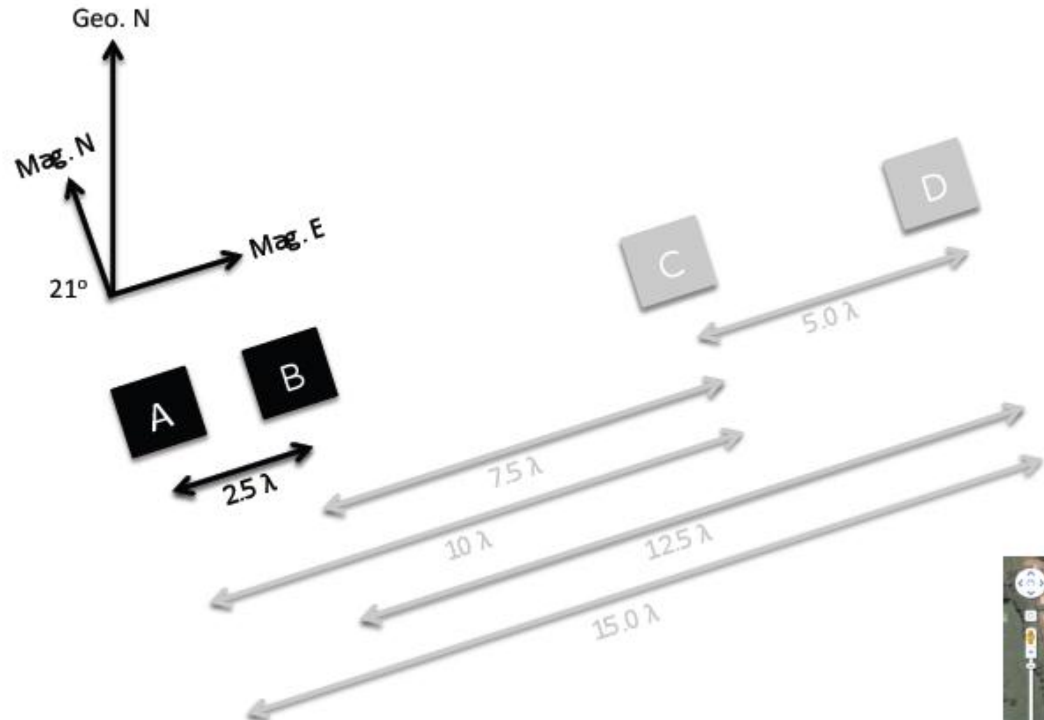


Bottom-type and plume onset time presents similar behavior for São Luís and Jicamarca however larger variation (onset time earlier for higher solar fluxes) for Christmas Island.

Plumes caracterization

Ionospheric irregularity zonal velocity calculation using VHF radar interferometry (in collaboration with Fabiano Rodrigues from UTD)

São Luís VHF radar antenna sets experimental setup



- Today: Single baseline observations

UTD

Plumes caracterization

São Luís VHF radar experimental setup

	150-km echoes*	**F-region***
TX power	4 kW	2x4 kW
Code length	28 bauds	28 bauds
Baud length	1 km	2.5 km
IPP	600 km	1,400 km
Initial sampling height	90 km	200 km
Max sampling height	210 km	875 km
Doppler velocities	± 40 m/s	± 268 m/s

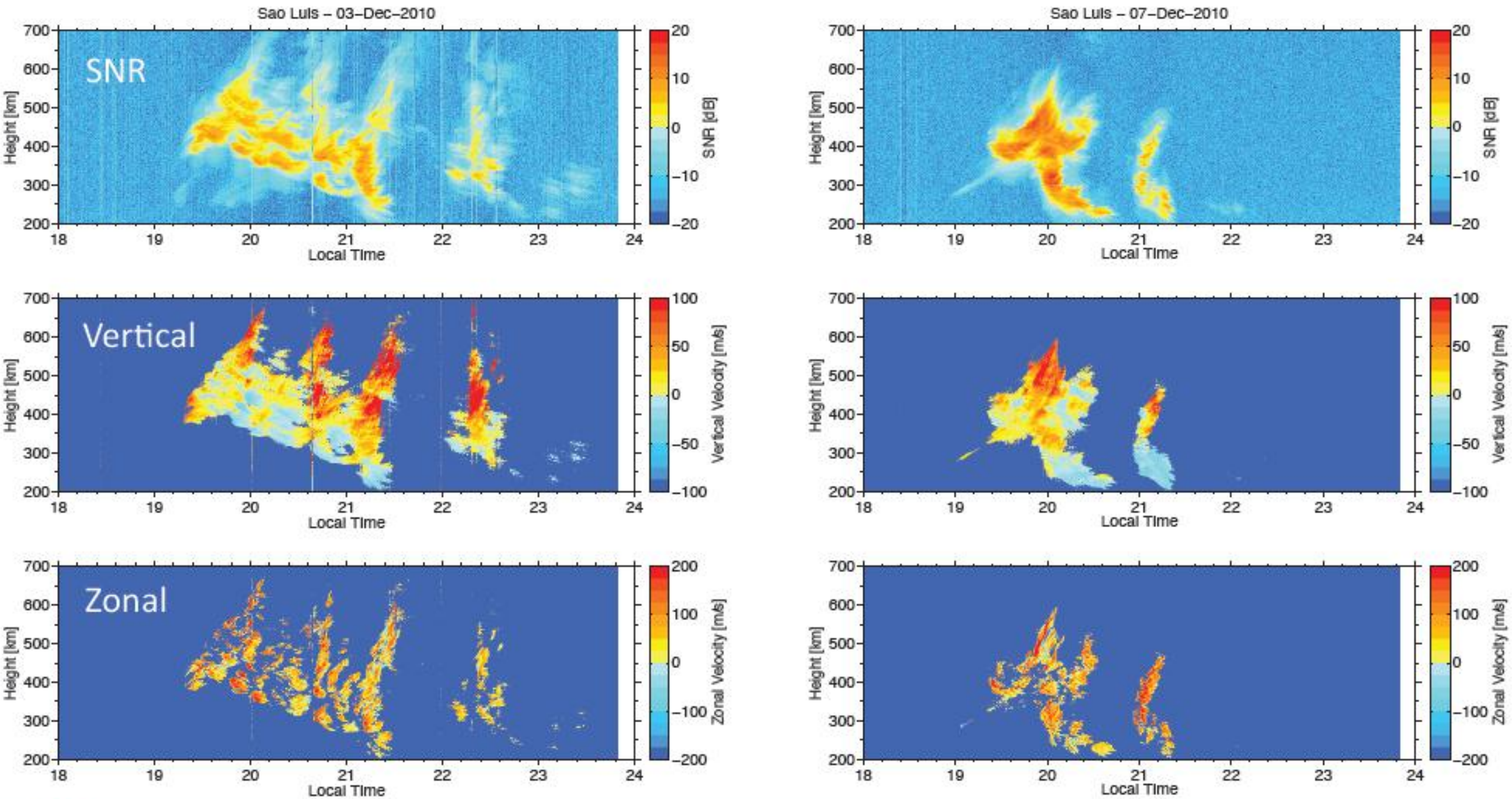
*Typical configuration

UTD

Plumes caracterization

Results

03-Dec-2010 07-Dec-2010

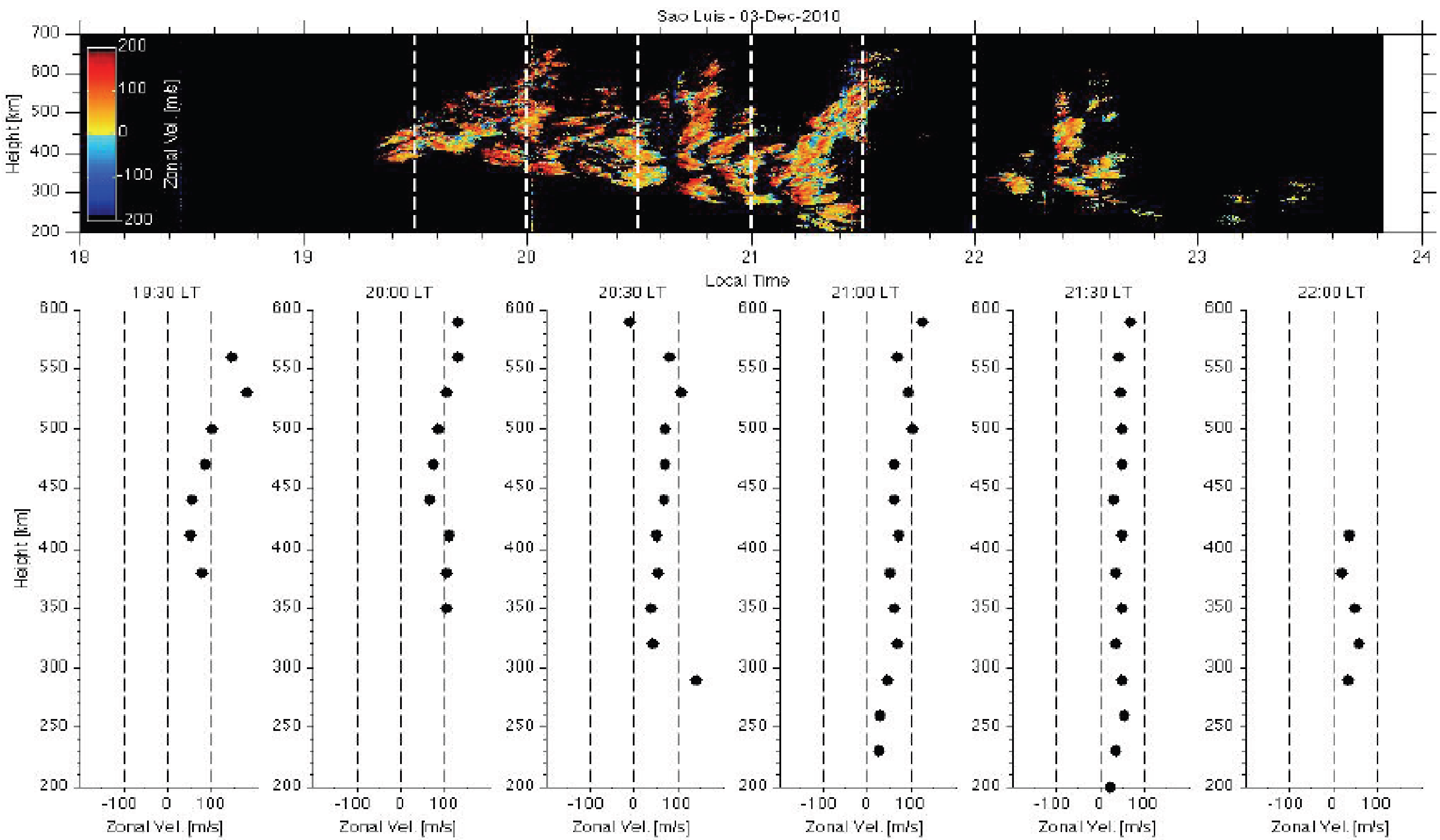


Plumes caracterization

Results

Relatively small height variation

03-Dec-2010

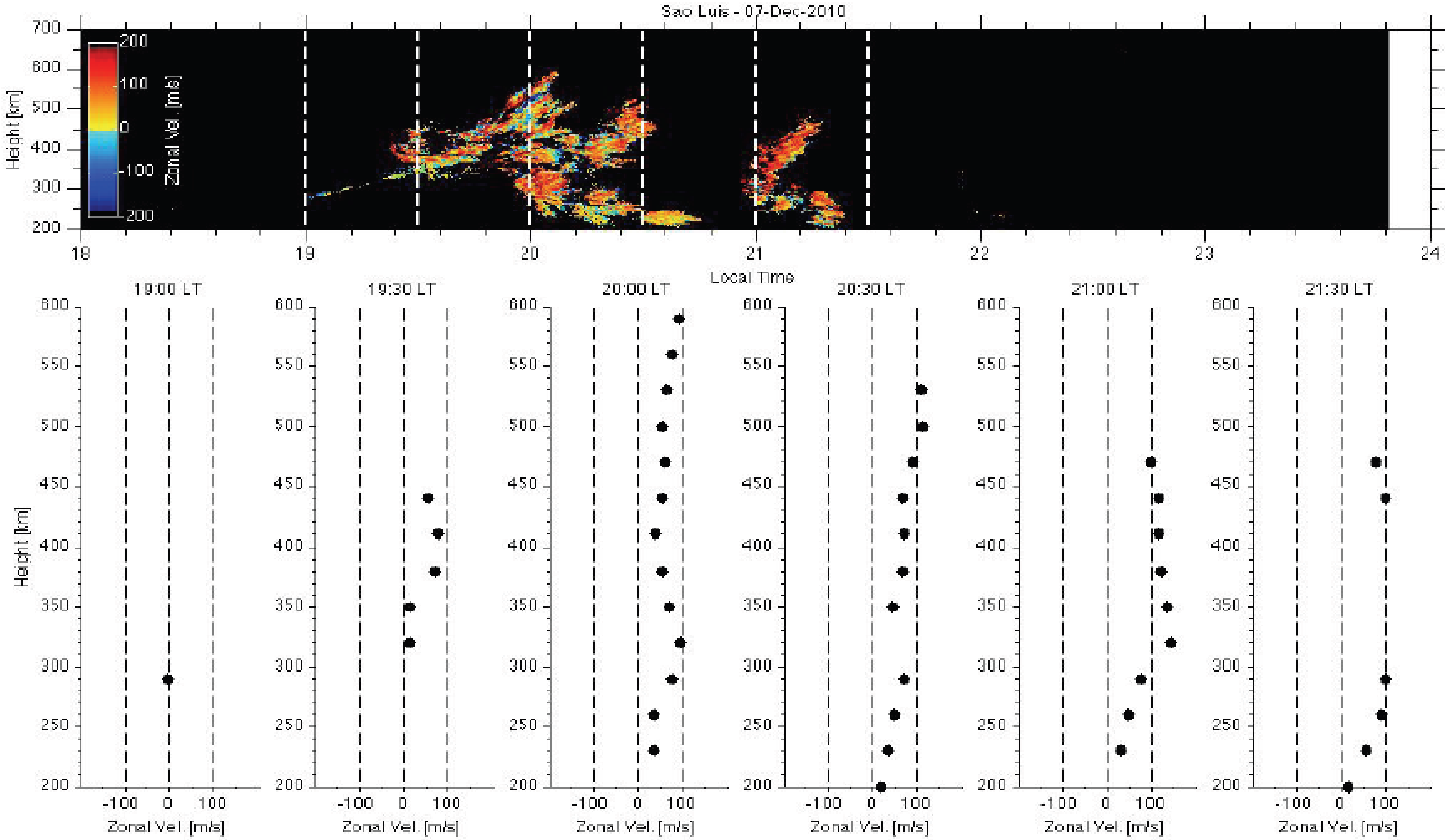


Plumes caracterization

Results

Slower drifts at lowest heights.

07-Dec-2010

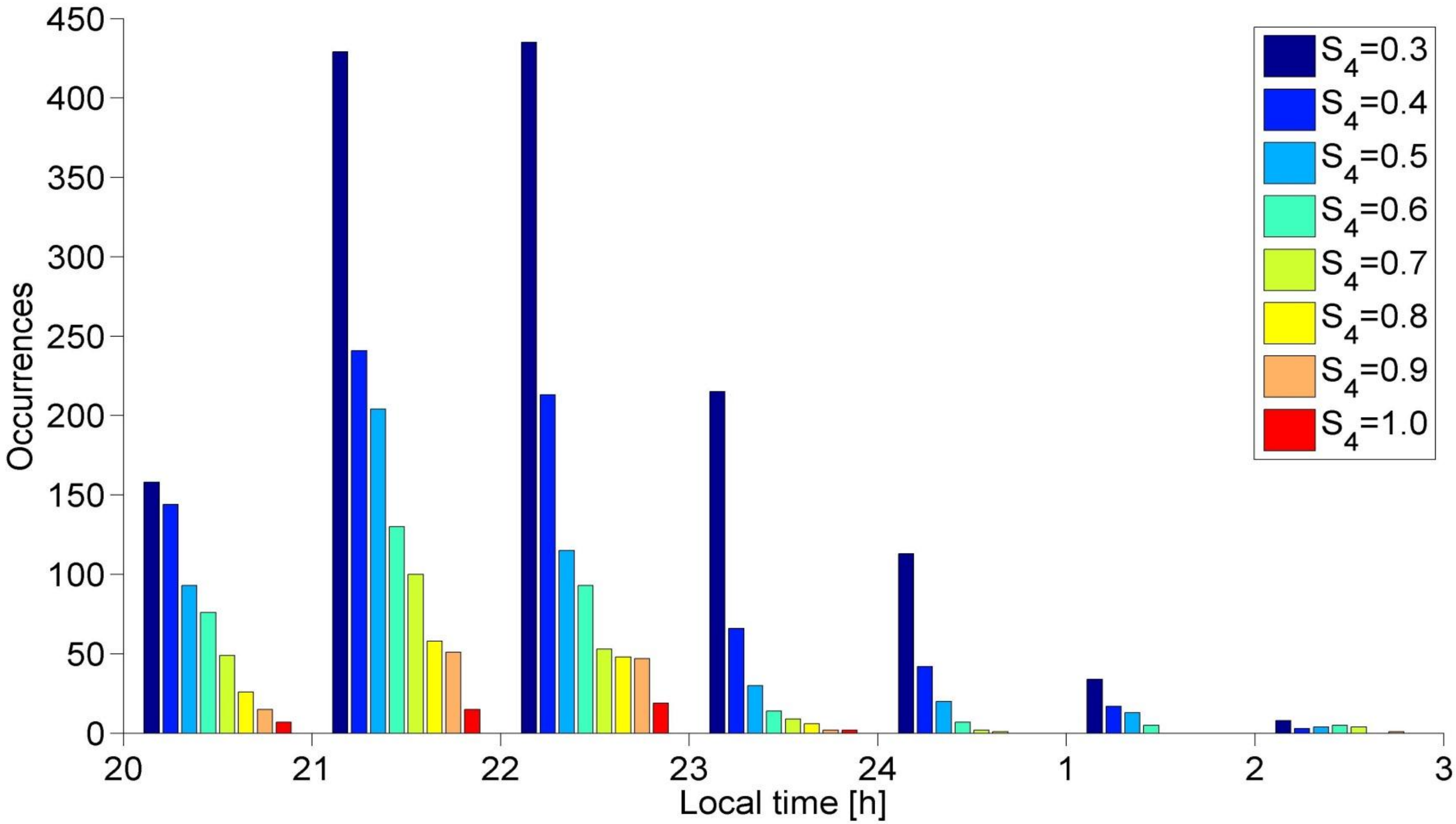


Conclusions for zonal drift calculations

- Results confirm the possibility of estimating <u>relative</u> zonal velocities.
  - Regions of westward drifts (bottomside F-region).
  - Determination of the height of the shear node (as high as 450 km).
- The turbulent nature of ESF, however, makes it less than straightforward to accurately determine the absolute mean bulk flow.
- Future work includes:
  - Long-term (several minutes) tracking of irregularity clusters to derive mean zonal drifts.
  - More comprehensive comparison, if possible, with plasma bubble velocities and winds.

GPS signal analysis

S_4 occurrences (in collaboration with Dr. Alison Moraes from IAE/CTA)



Distribution of the S4 indices of the observations available between Dec 14th 2001 and Jan 14th 2002, as a function of local time.

GPS signal analysis

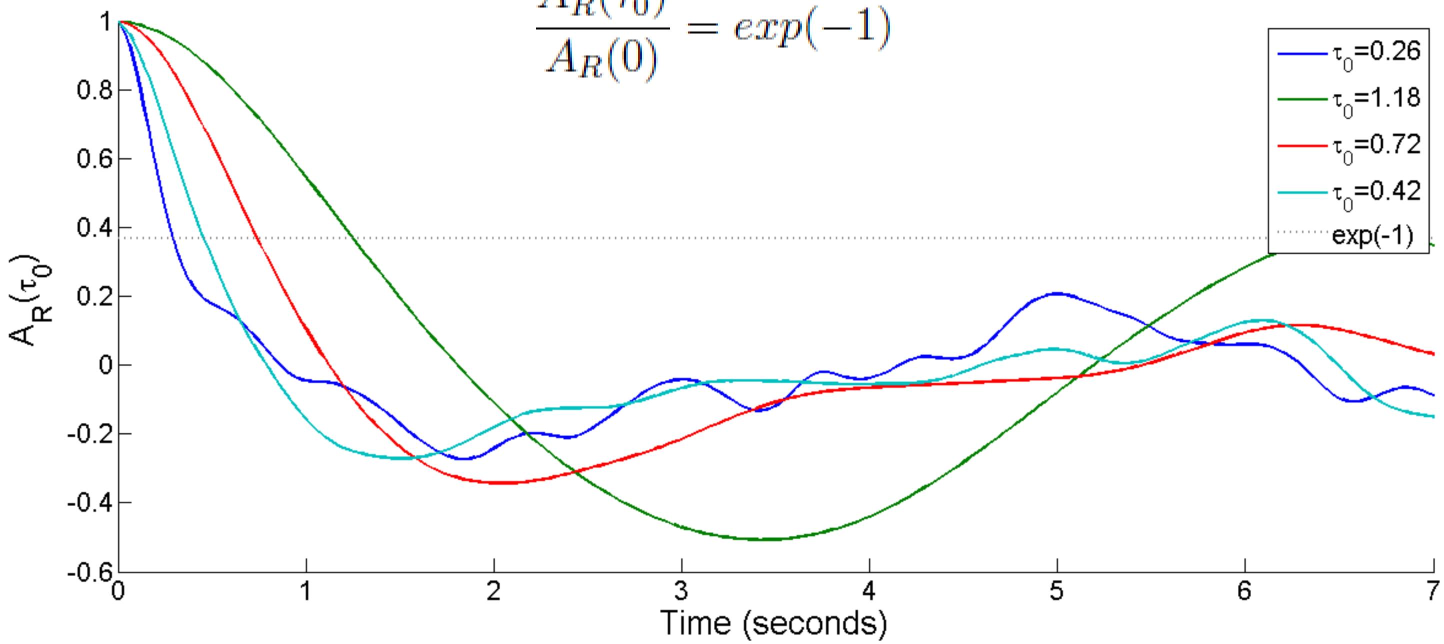
Decorrelation time

The autocorrelation function of the normalized signal amplitude scintillation is given by

$$A_R(\tau) = \frac{E[(R(t)-z)(R(t+\tau)-z)]}{\sigma_R^2}$$

The τ_0 value is defined as the time lag at which the autocorrelation function falls off by e^{-1} from its maximum (zero lag) value:

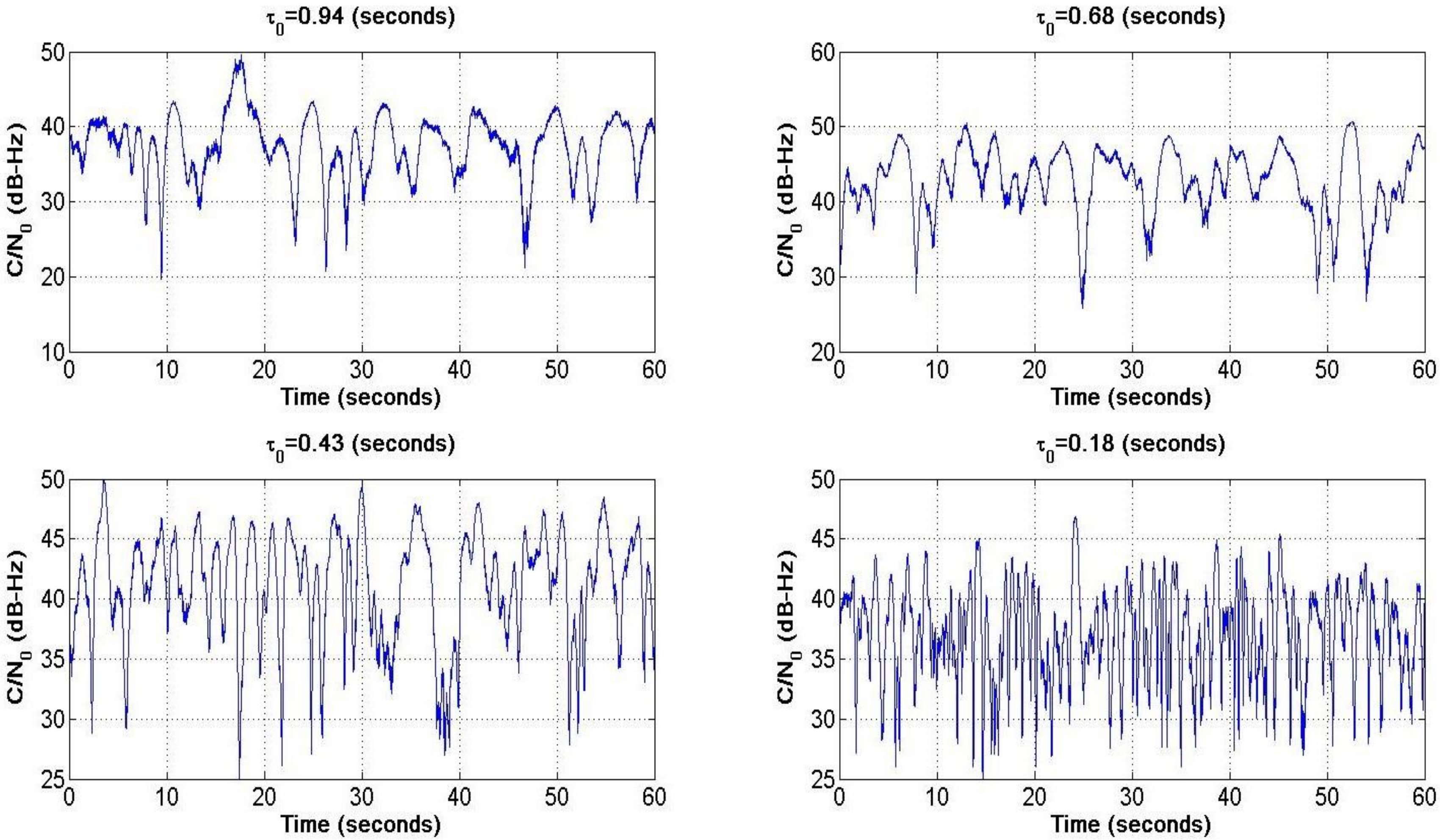
$$\frac{A_R(\tau_0)}{A_R(0)} = exp(-1)$$



While the S_4 index is an indicator of the depth (or magnitude) of amplitude fadings, the decorrelation time (τ_0) is an indicator of rapidity of the fadings.

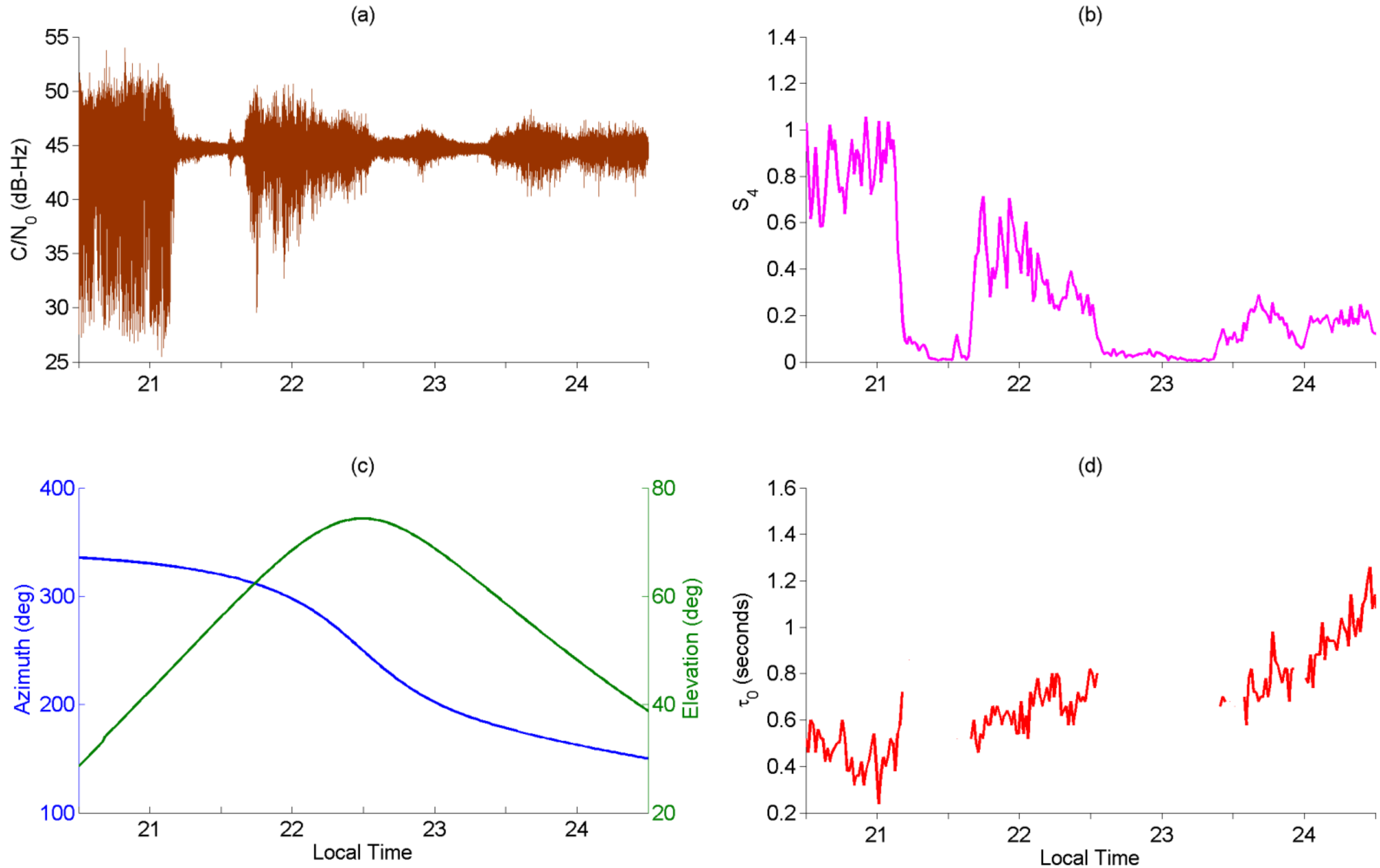
GPS signal analysis

The variability of amplitude scintillation patterns



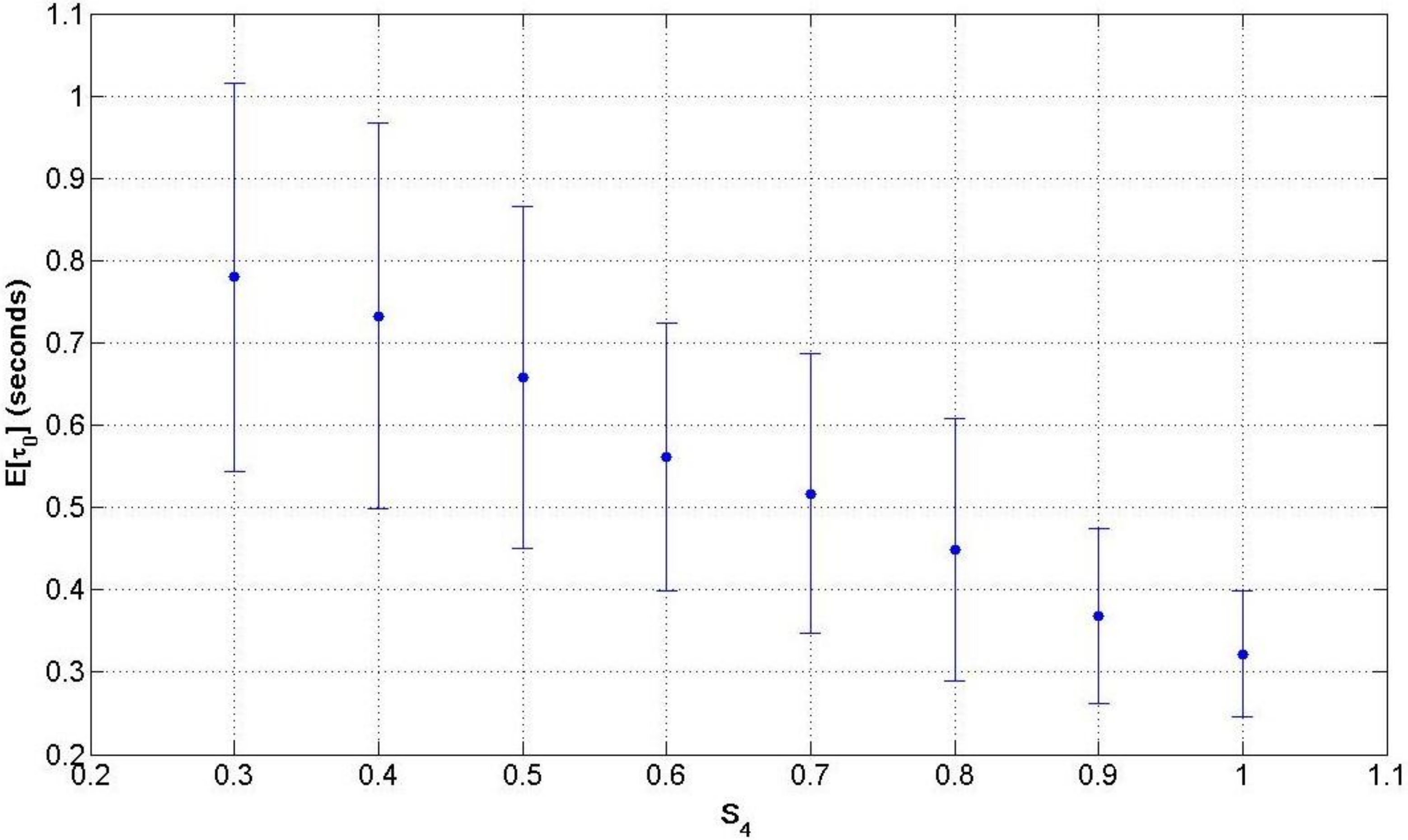
Examples illustrating the variability in the decorrelation time made during the campaign of observations used in this study. In all cases the time series of measured signal amplitude have approximately the same S4 (~0.9), but very distinct $\tau 0$ values

GPS signal analysis
Example of observations



Sao Jose dos Campos on December 14th, 2001. Panel (a) C/N0 of the L1 signal received from satellite PRN 28. (b) S4 index. (c) azimuth and elevation angle of the PRN 28. (d) decorrelation time ($\tau 0$) (is not computed for S4<0.1). This example illustrates that the scintillation intensity decreases and the decorrelation time increases as time progresses.

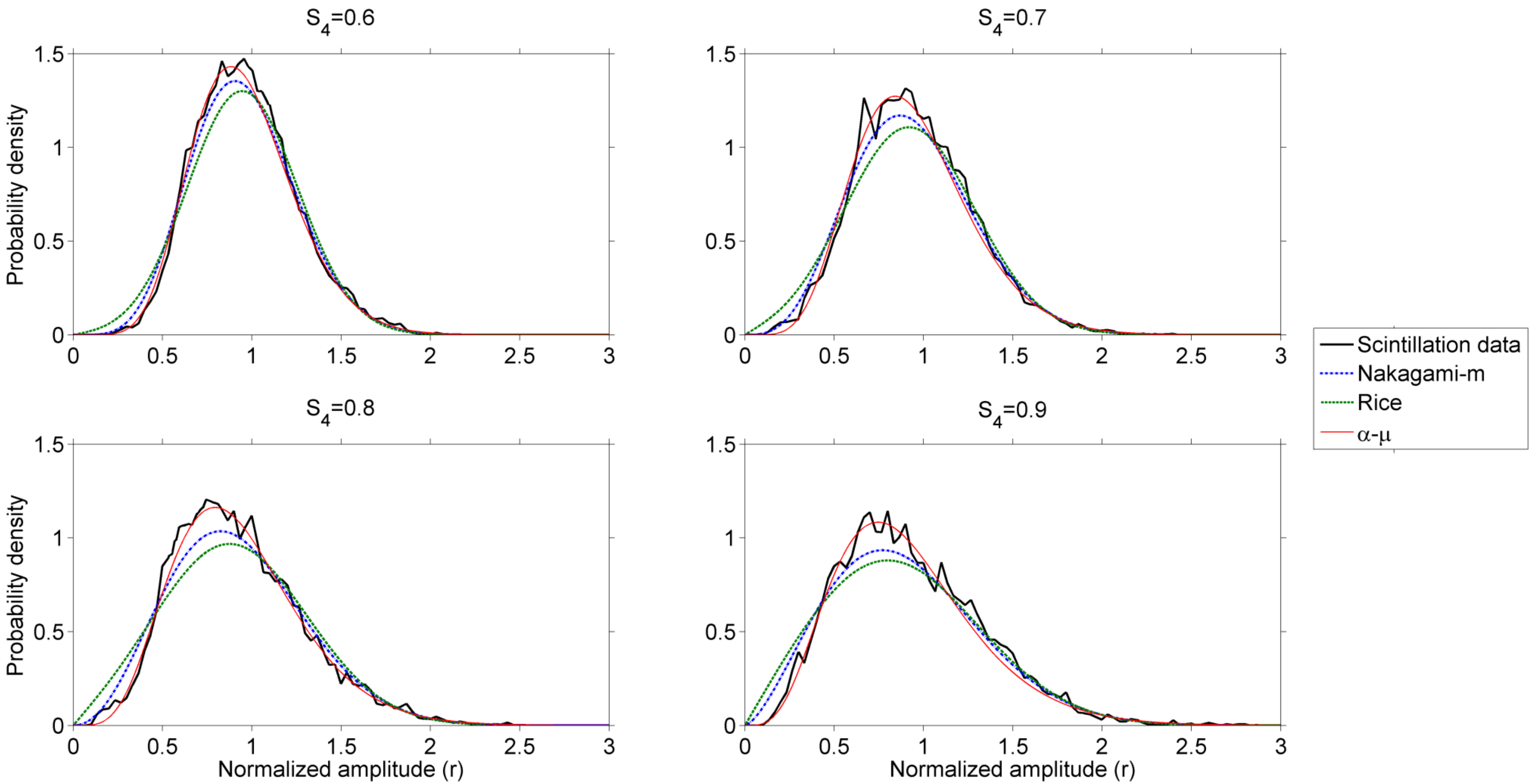
GPS signal analysis
S_4 vs τ_0



- Linear relationship between S4 and τ0;
- Variability/spread of τ0 values as well as the mean value of τ0 tend to decrease as scintillation intensity (S4) increases.
- Decorrelation times decreases as scintillation becomes stronger, and vice versa.

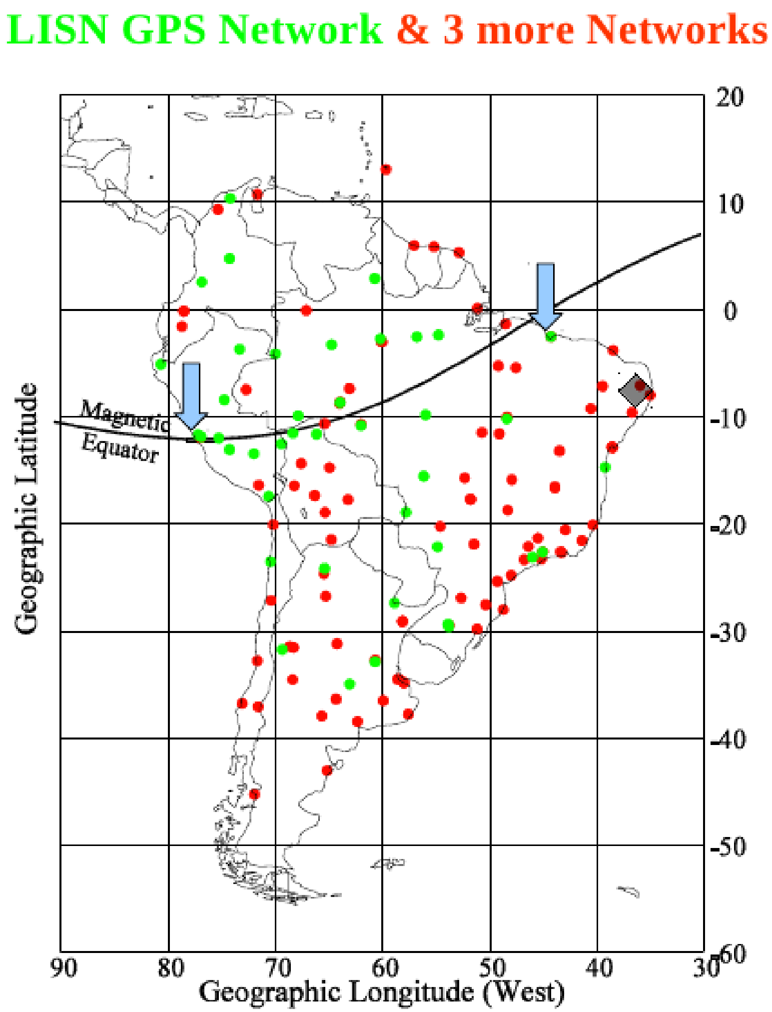
GPS signal analysis

Amplitude distributions



- α-μ distribution (Yacoub, 2007). This model assumes the signal as a composition of many clusters of multipath waves instead of just one. The result of such an assumption is a more comprehensive characterization of electromagnetic scattering phenomena.
- Our results show that the Nakagami-m PDF performed better than the Rice PDF
- α-μ distribution, however, outperformed the Nakagami-m and Rice PDFs for all cases.

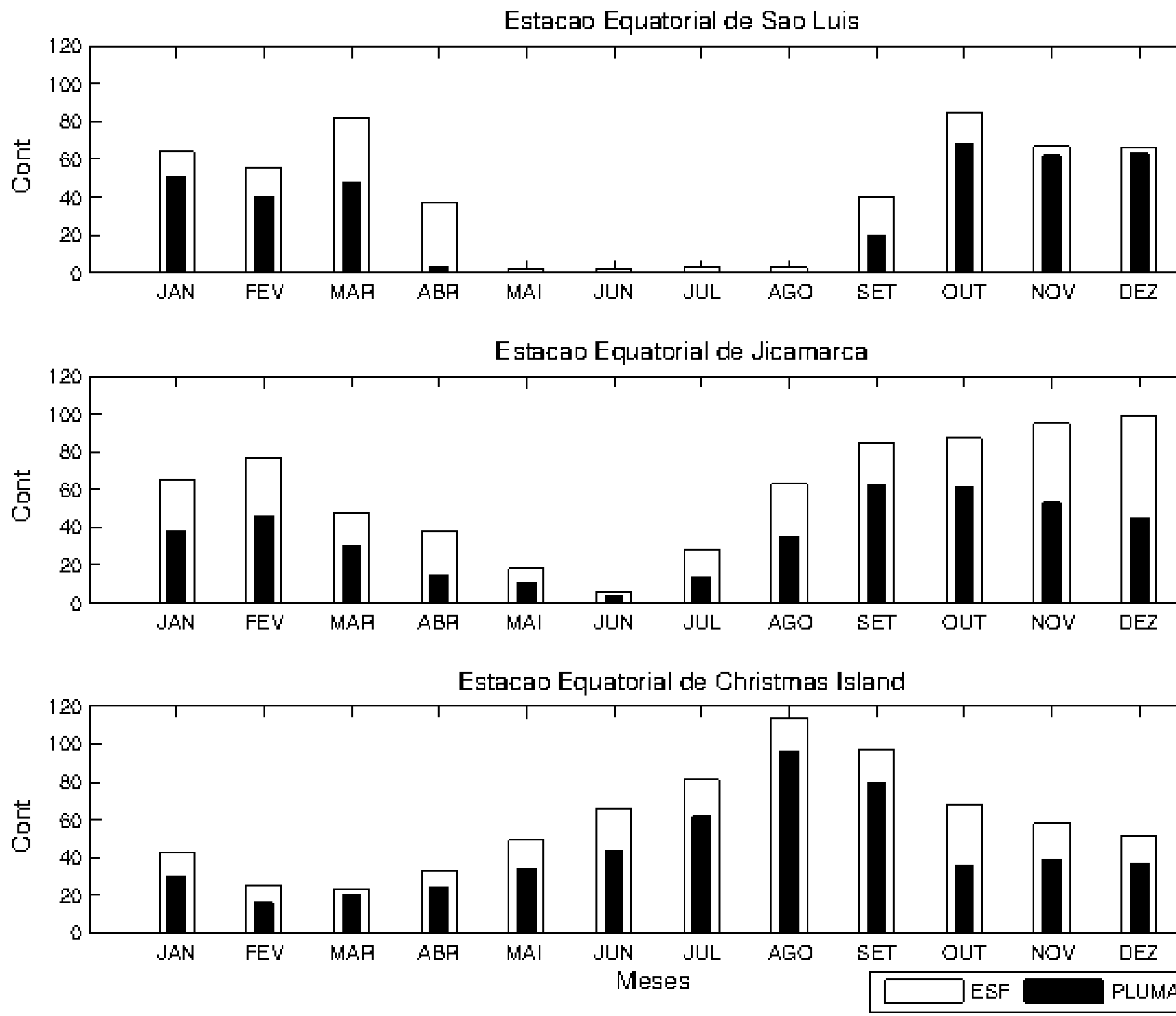
Ionospheric scintillation using GPS over South America



LISN GPS Network (in green) & 3 more Networks (in red). The gray arrows indicate the Jicamarca and São Luís digisondes, the diamond indicate the position of the imager at São João do Cariri.

Ionospheric scintillation using GPS over South America

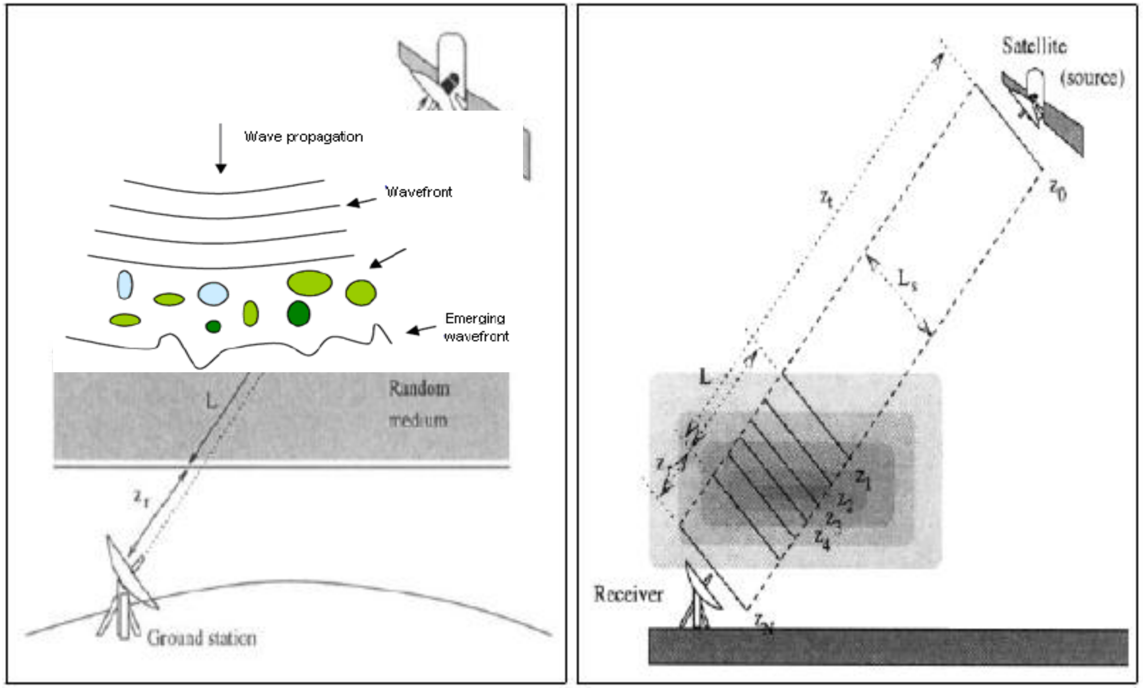
Seasonal percentage of scintillation occurrence for 3 stations



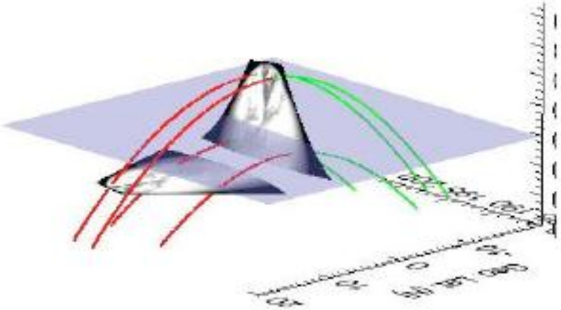
Black histogram: Observed plumes and white histogram: Spread F. At São Luís plume occurrence is from September to March with a peak at summer. At Jicamarca the peaks are at equinoces and for Christmas Island is on August.

The difference between black and white bars represent bottom-type structures.

Irregularity prediction model(Emanoel Costa/Ricardo Yvan)



- Radio waves passing through the irregularities diffract producing signal fading and strong scintillations even at L frequencies.
- The contribution in the model was made in mapping the irregularities along the magnetic field lines.

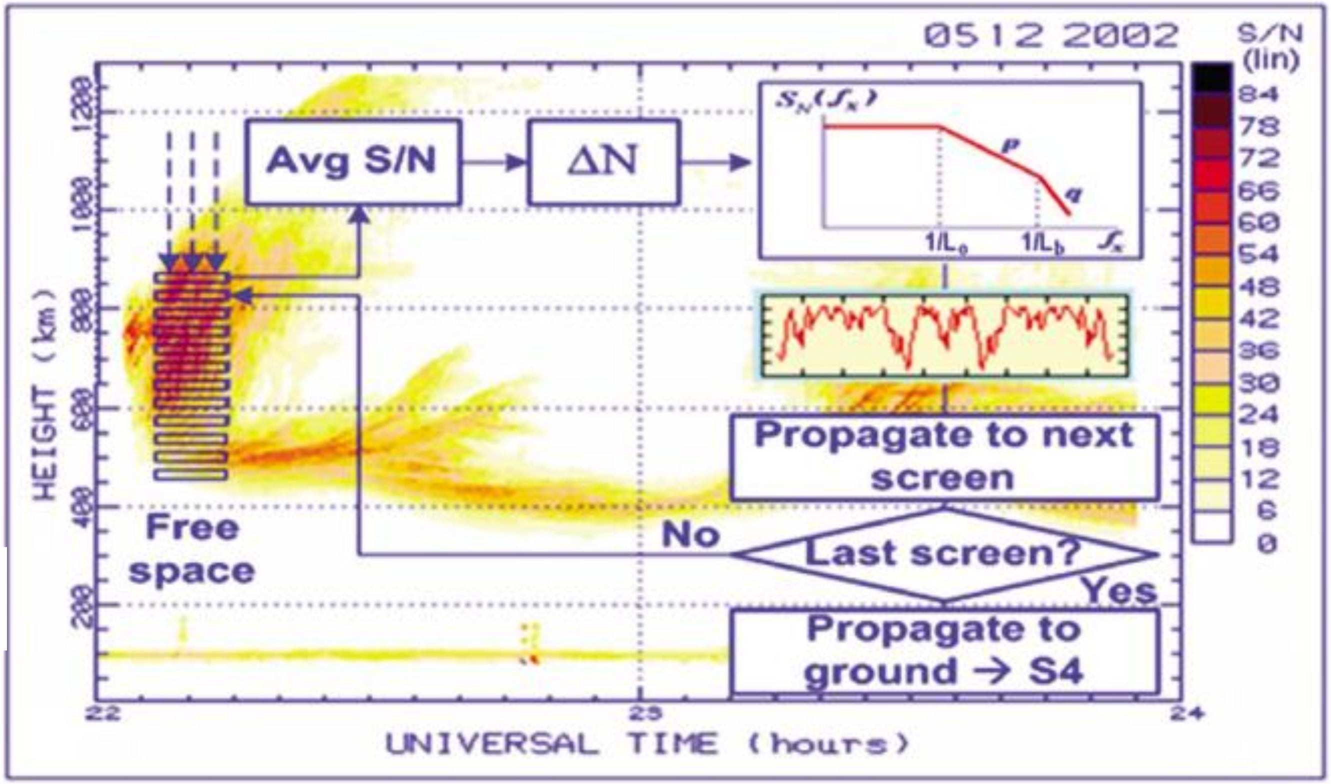


Irregularity prediction model(Emanoel Costa/Ricardo Yvan)

Range-Time-Intensity maps from the São Luís coherent scatter radar will be used to predict time variations of the scintillation index S4.

The model use the s/n ratio measurements by the VHF radar to estimate the mean square electron density fluctuation within the corresponding volume.

$$S4^2 = \frac{< I^2 > - < I >^2}{< I >^2}$$



We are using zonal drift velocity from climatological model (Arruda et al., 2006). V = 150m/s between 19-23 UT, 80 m/s between 23-29 UT.

Irregularity prediction model(Emanoel Costa/Ricardo Yvan)

$\langle \Delta N^2 \rangle$ Mean Square Electron Density

S/N Signal to Noise ratio

$$\sqrt{< \Delta N^2 >} \approx \frac{2\pi}{r_e}\sqrt{\frac{k_B T_{sky} B_N L_{tot}}{G^2 \overline{g^2}\theta_{3\perp}\delta h_r(\lambda_r/2)^3 P_t}}\sqrt{\frac{\pi S_1 L_o^{p-2} L_b^{q-p}}{(\lambda_r/2)^q}}\, r\sqrt{(s/n)} \approx CteRadar.r.\sqrt{(s/n)}$$

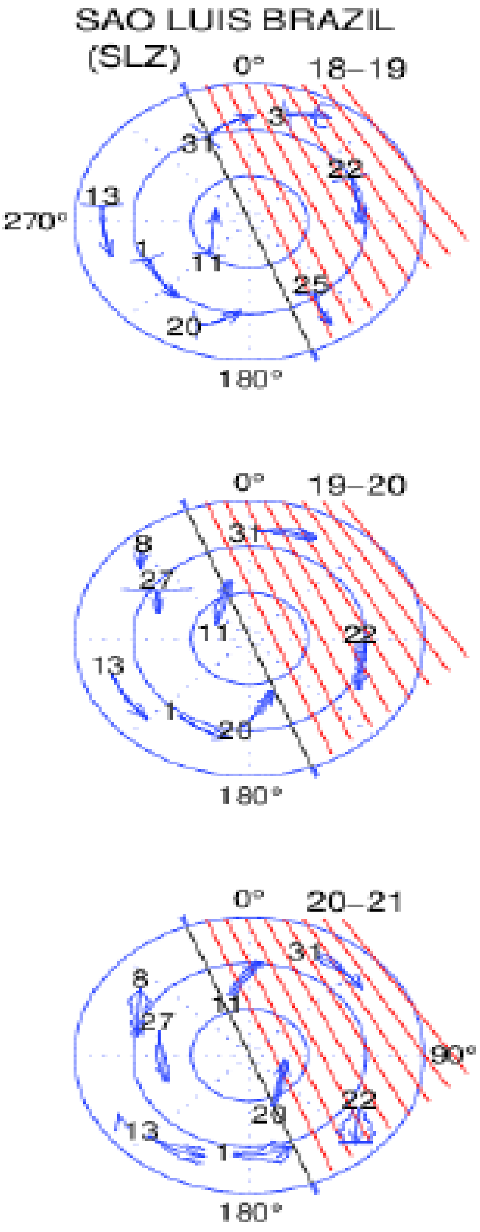
Power Spectral Parameters

Obtained from C/NOFS satellite for 2008

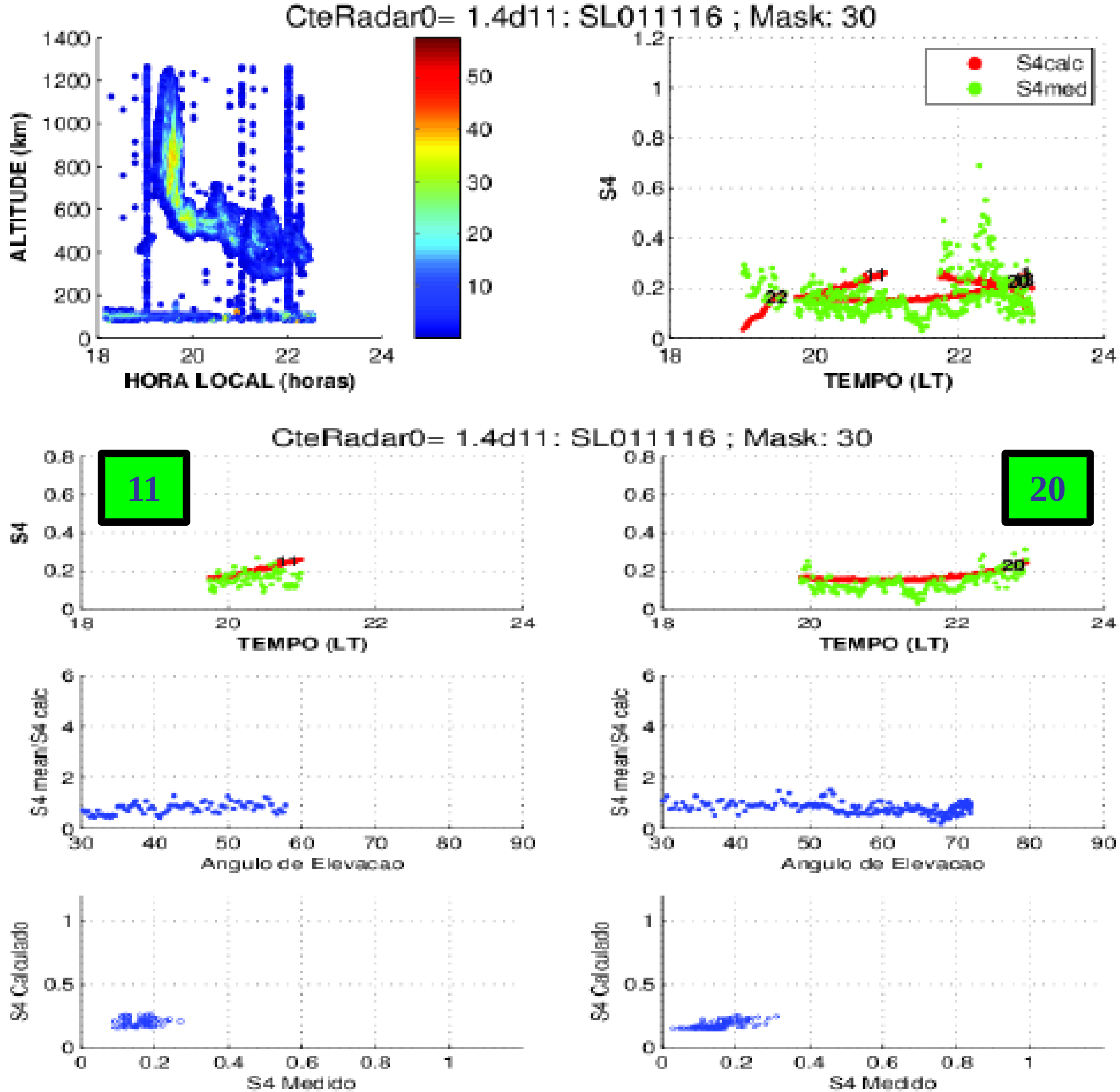
Radar Parameters

Parameters	Values
$L_o[km]$	12.500
$L_b[km]$	0.080
p	2.600
q	4.600
$S1$	3.210
$Freq[MHz]$	29.795
$Pt[kW]$	4.000
Eff	0.500
$dh[km]$	2.500
$BW3dB[deg]$	10.000
$Gain[dBi]$	26.000
$NFig[dB]$	5.000
$Tsys[K]$	917.061
$Tsky[K]$	10000.000
$BW[kHz]$	120.000

Irregularity prediction model(Emanoel Costa/Ricardo Yvan)



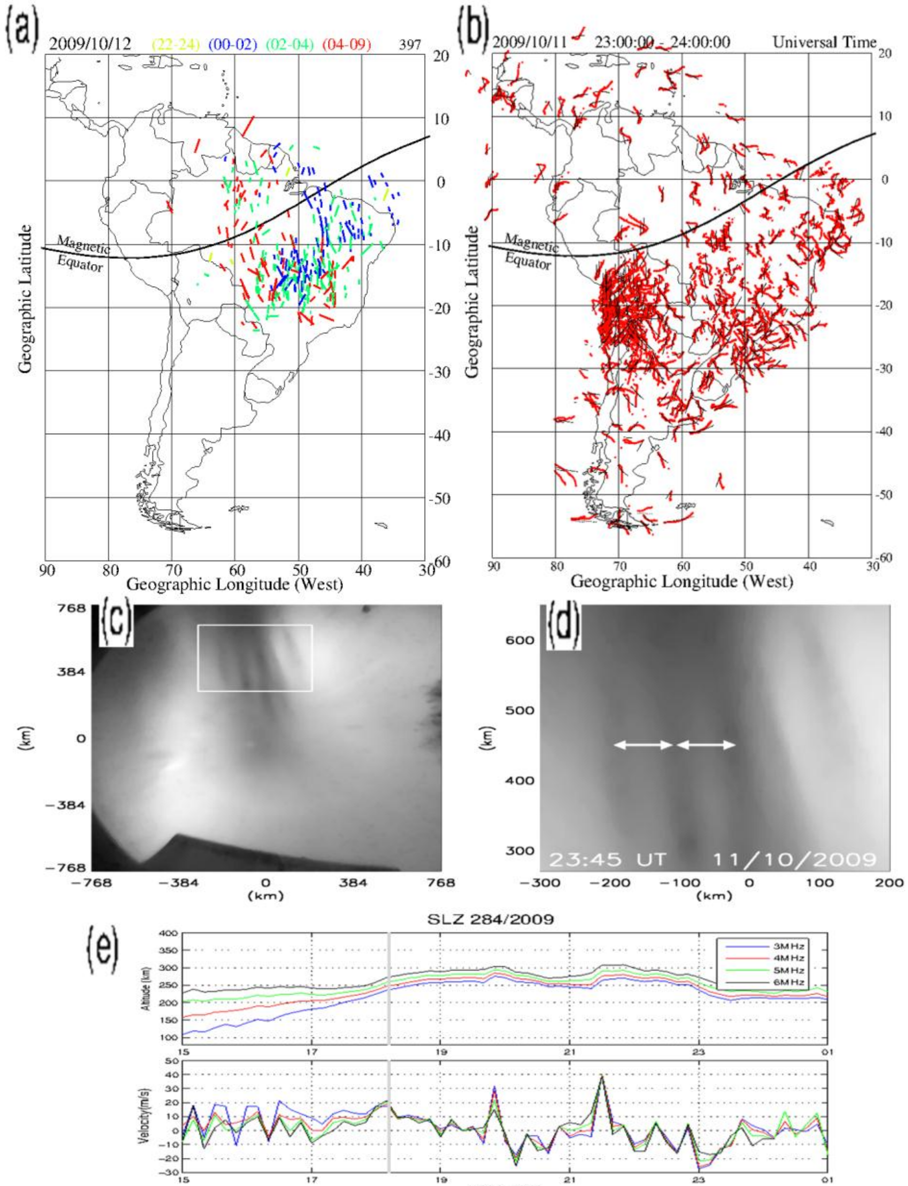
S4(measured x calculated) for PRN 11 and 20 16 Nov. 2001



Irregularity prediction

Ionospheric irregularity precursors (prediction tentative)

Influence of MSTIDs and GWs on the irregularity generation (Ricardo´s PhD)



(a) - TEC depletions

(b) - TEC disturbances(TIDs)

(c) - OI630 nm images

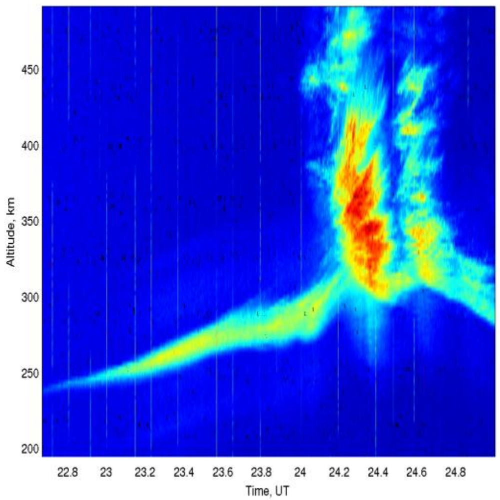
(d) - Bubble separation

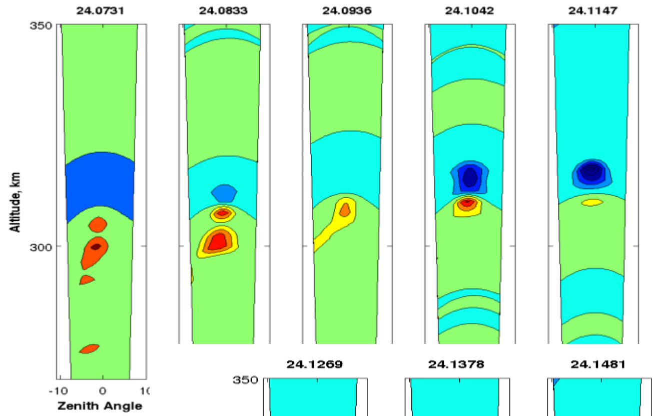
(e) - Digisonde altitude and drift velocity

Wave oscillations of about 30 minutes were observeds which give evidency of gravity waves(GW)

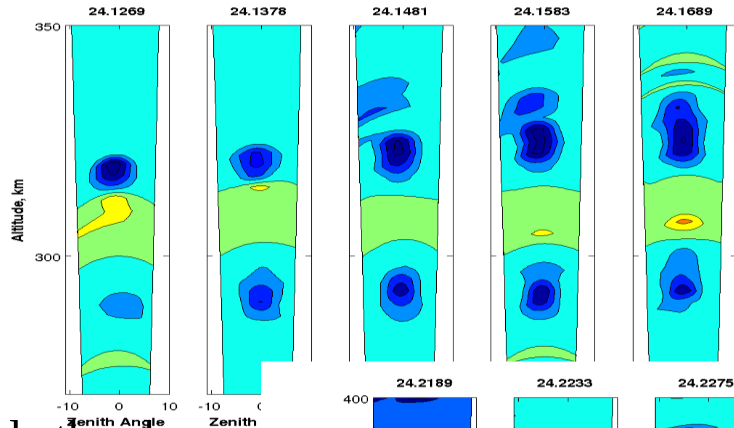
Irregularity prediction(Precursor)

Irregular base layer dynamics before the bubble triggering using radar imaging
(in collaboration with Alam Kherani from INPE)

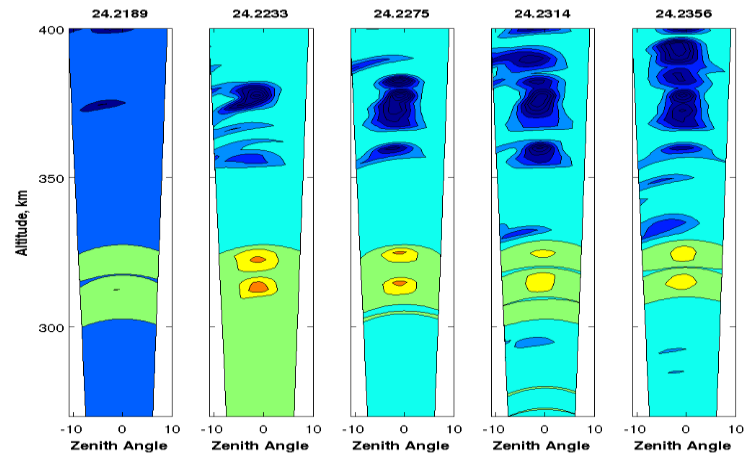




Irregularity initiation in the base layer probably generated by the Rayleigh-Taylor and shear instabilities



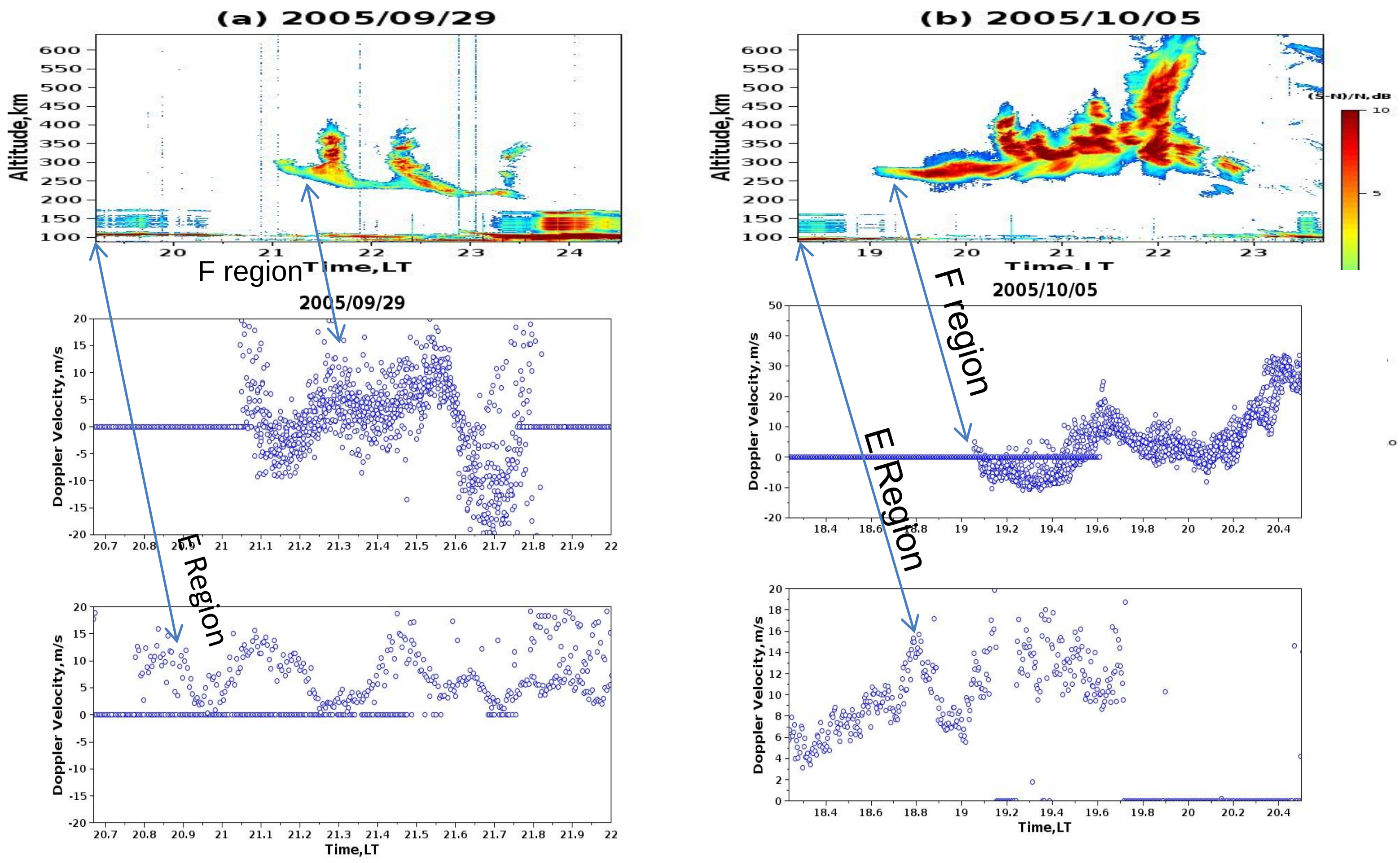
With time this layer grows upward outside the shear region and becomes a bubble.



The bubble can grow in altitude, detached from the base layer.

Irregularity prediction(Precursor)

Irregular F and E layers dynamics before the bubble occurrence using VHF Radar



The Doppler velocity inside the irregular F layer shows wavy behavior.
Similar behavior was observed in the irregular E layer with a time shift prior to the F layer.
And this E layer behavior could be considered as a precursor of the bubble.

Irregularity prediction

The following procedures can also be used to predict irregularities:

- Ionosonde vertical drift calculations to establish thresholds to trigger irregularities (this work is being developed).
- Bubble velocity is eastward (during quiet period) so spaced GPS receivers / VHF receivers in the zonal direction (SCINDA) can be employed to predict bubble occurrence to eastward station.

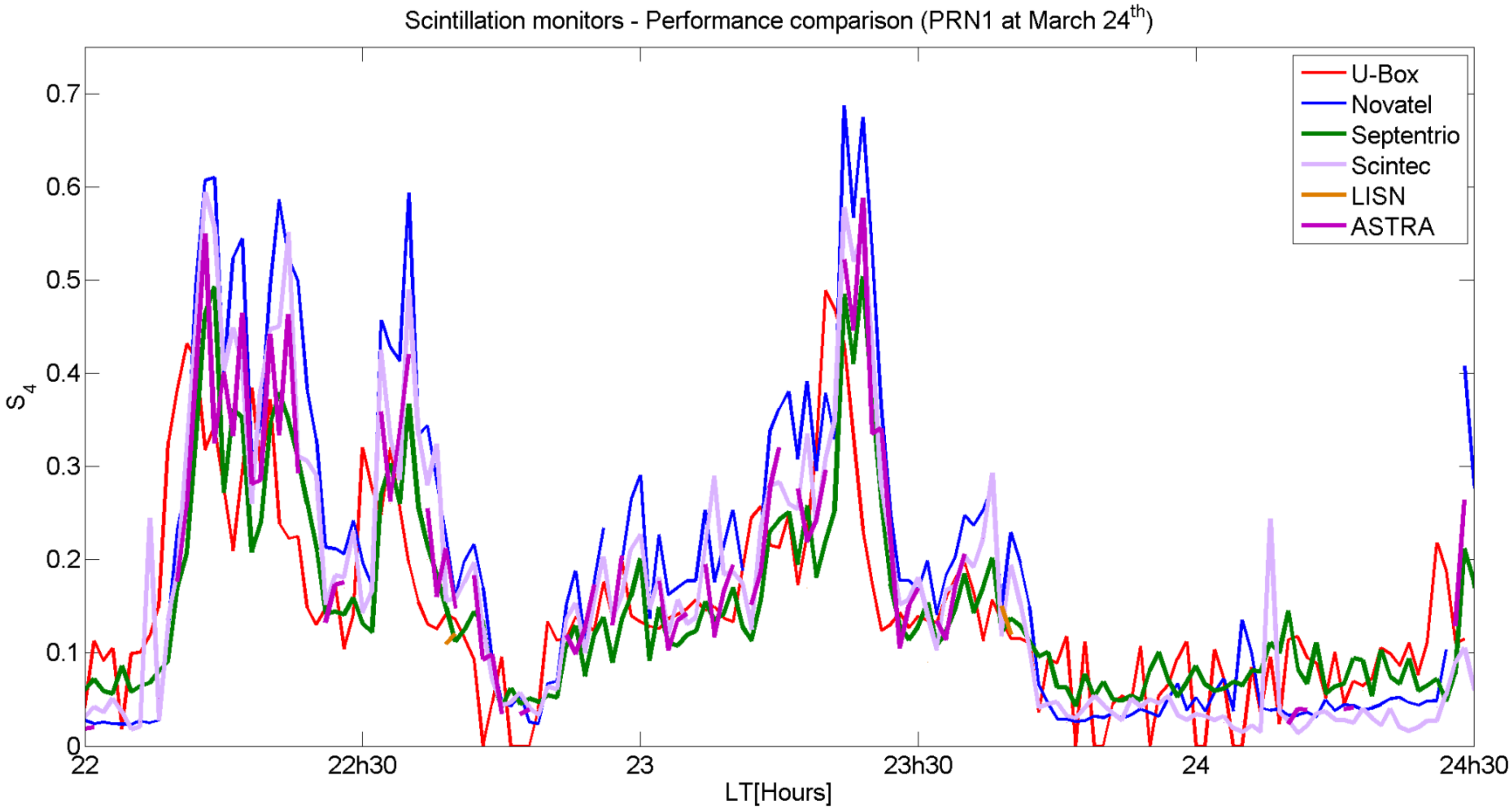
6 different GNSS receivers campaign

To analyze their behavior under scintillation condictions (Septentrio, Novatel 4004B and GPS-Station6, ASTRA,GEC-PLESSEY Card – Cornell, Stanford - U Box) Keith Groves, Cesar Valladares, Todd Walter, Geoff Crowley, Paul Kintner†

Campaing of 6 different GNSS receivers(Stanford)

6 different GNSS receivers campaign

Different GNSS receivers behavior under scintillation conditions during March 24 2013 at São José dos Campos, São Paulo - Brazil



Good S4 agreement for the 6 receivers and for moderate scintillations – no strong scintillations tested

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